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THE 2 MICRON ALL-SKY SURVEY

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Abstract. The 2 μm All Sky Survey, or 2MASS, will cover the sky at three near-infrared wavelengths (J, H, and K_s) with a pixellation of ~2.0" One of the primary science goals of the survey is to produce a catalogue of galaxies to a limit between K=13 and K=14 (equivalent to B=16-17) to within 10° of the galactic plane. The 2MASS Galaxy Catalogue is expected to contain over a million galaxies and will be an invaluable aid to mapping the local density field out to z=0.1.

1. Introduction

One of the major current problems in cosmology is the lack of understanding of the cause/source of our motion with respect to the cosmic microwave background radiation (e.g. Smoot *et al.* 1991). This lack of understanding is evidenced by the large number of often contradictory results on the local flow field (Lynden-Bell *et al.* 1988; Scaramella *et al.* 1991; Lauer and Postman 1994). Attempts at resolving this issue *via* the combination of maps of the velocity field and of the galaxy density field so far have been hampered by either the sparseness of the samples, their lack of depth, and/or their lack of sky coverage. The IRAS QDOT (Rowan Robinson *et al.* 1990) and 1.2-Jy (Strauss *et al.* 1992) samples, while having good sky coverage, do not densely sample the field and contain only spiral galaxies, which are known to be biased away from high density regions. The optical surveys (Lahav and Scharf 1993), while less biased by morphological type, and more dense (e.g. Geller and Huchra 1989; Marzke *et al.* 1994), are significantly affected by galactic extinction. Reconstruction of the density field from the velocity field and *vice versa* has only been done on small scales and with relatively crude (~1000 km/sec smoothing scales) spatial resolution (Bertschinger and Dekel 1989; Dekel *et al.* 1993). Perhaps one of the largest difficulties with these attempts is that the direction of the microwave background motion, after correction to the centroid of the Local Group, is only 30° from the galactic plane.

In order to address this problem more directly (as well as to provide good samples to attack a broad spectrum of galactic and extragalactic astrophysical problems), we are about to conduct a digital all-sky survey in the near-infrared in three bands. The advantages of such a survey for mapping the local galaxy density field are obvious. Firstly, the survey uniformity down into the galactic plane is considerably improved over optical surveys because $A_K = 0.07A_B$. Secondly, a near-IR survey is much more "morphology blind" than either optical or IRAS surveys. Galaxy energy distributions for almost all types of galaxies peak near 1.6 μm (Aaronson 1978). In addition, near-IR wavelengths sample the stellar mass distribution much better than blue or 60 μm wavelengths, which can be (are!) dominated by young stellar components that represent only a small fraction of a galaxy's mass. Remember that the primary relation that we are attempting to apply while mapping large scale flows and density fields is the fact that both light and gravity fall off as $1/r^2$ — if the "light" we are measuring is only weakly related to a galaxy's mass (e.g. 60 μm radiation which comes primarily from hot dust), then perhaps it is not fair to use samples selected in such a manner to provide definitive cosmological answers.

Lastly, providing uniform photometry for a large sample of objects is absolutely necessary because small errors in photometric zero points can translate into apparent density variations that are significant on the clustering scales we need to examine (e.g. de Lapparent, Kurtz and Geller 1986). Photographic surveys have well known zero point and linearity problems. In addition, a digital survey such as 2MASS, can provide accurate magnitudes for individual galaxies for use in applications like the infrared Tully-Fisher relation. We intend to use these for the measurement of the Hubble constant *and* to better determine the very galaxy velocity field we are trying to understand through the density field.

2. SURVEY IMPLEMENTATION

The critical parameters for 2MASS are listed in Table I. The survey will operate simultaneously in two hemispheres (to achieve full sky coverage) and in three near-infrared wavebands. The observations will be carried out with a pair of 1.3m telescopes which will be optimized for the needs of the survey, and are fully dedicated to the survey execution. Each telescope will be equipped with a camera containing three infrared array detectors.

The arrays will record images with a pixel scale of 2.0″/pixel. The integration time is set so that the observations are background-limited in all three wavebands; OH airglow dominates the background in the J and H bands, while thermal emission from the telescope also contributes to the K_s-band background. The survey specifications call for the detection of point sources with $K_s \leq 14.0$ mag. at $\geq 10\sigma$.

A novel mapping strategy, dubbed "freeze-frame scanning" by Frank Low, is used to scan the sky. In this scheme, the telescope tracks in Right Ascension, while executing a smooth scan in Declination. The secondary mirror is moved in a sawtooth pattern, such that during the slow sweep of the secondary, the image of the sky is frozen onto the focal plane. At the end of the slow sweep (which typically takes about 1.5s) the secondary is moved quickly back to its starting point, but the telescope is pointing to a new location. The scan rate is

chosen such that the new location is displaced only 1/5th of the field from the previously imaged field, so that 5 separate images are obtained for each field on the sky. The array is slightly tilted with respect to the scan direction, to improve the intra-pixel sampling. This scheme minimizes the effects of bad pixels, and improves both the photometric and positional accuracy.

To test the survey mapping strategy, measure the backgrounds, and determine some critical astrophysical parameters needed to optimize the design of the survey, a prototype camera was built in 1992 at Infrared Laboratories. This camera contains only a single, 256x256 HgCdTe array, and therefore maps in only 1 band at a time. The prototype camera is capable of surveying the sky at a rate of 13 square degrees per hour. This implies a required survey duration of approximately 2000 photometric hours to map a hemisphere or between 500 and 1000 nights of time, 2-3 years, if weather is factored in.

Table 1. 2MASS Parameters

	Survey Parameters	*Prototype Camera*
Wavebands	J, H, and K_s	J, H, or K_s
Sky Coverage	$4\,\pi$ sr	800 sq. deg. (to date)
Pixel Size	$2.0'' \times 2.0''$	$2.3'' \times 2.3''$
Sensitivity	$K_s \leq 14$ mag., 10σ	$K_s \leq 14$ mag., 14σ
Photometric Accuracy	$\leq$5% for $K_s \leq 12.5$ mag.	$\leq$5% for $K_s \leq 12.5$ mag.
Positional Accuracy	$\leq 1.0''$	$\sim 0.5''$

3. PROTOTYPE CAMERA RESULTS

We have used the prototype camera to survey several dozen areas of the sky, including regions around the Orion Molecular Cloud, Coma, and a section of the galactic plane at b=0° and l=53° (19^h27^m +17°42^m where we have also digitized the Palomar B and R plates for comparison. This comparison is shown in Figure 1. It is easily seen that the 2MASS scans, even though short in total integration time, probe considerably deeper in and/or through the plane than optical photographic surveys.

One issue that has been raised is the ability to detect galaxies at low galactic latitudes with our moderately coarse pixellation. The initial survey of the plane is likely to be done with 2$''$ pixels. While it is difficult to know exactly what our limits will be as a function of galactic latitude, we can get some qualitative feeling by looking at one or two well known objects. Figure 2 shows our survey mode image of Maffei 2. This can be compared to your favorite optical image of the galaxy.

A test of the ability of 2MASS to detect galaxies at high galactic latitude was performed by observing the core of the Coma cluster. Figure 3 shows the survey mode K_s-band image. Comparison of this image with the POSS-E (red)

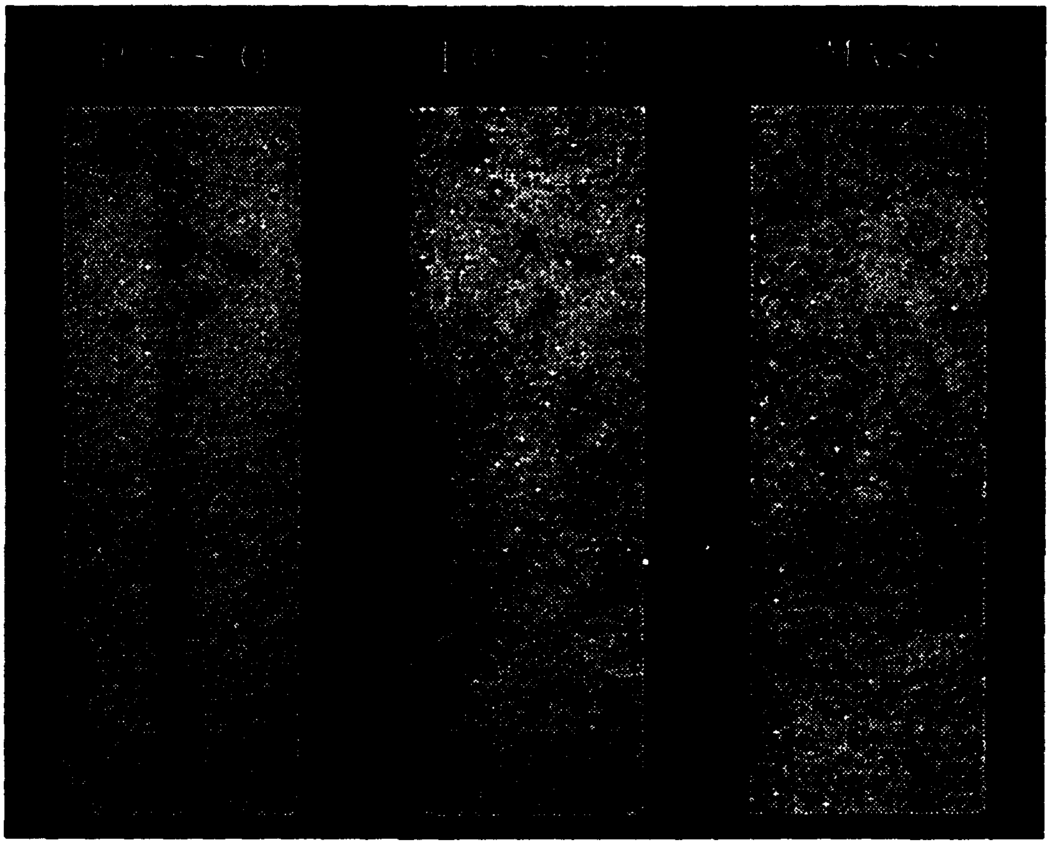


Figure 1. North-South scans of a region of the Galactic plane at $b=0^\circ$, $l=53^\circ$, between $17^\circ\!.32' < \delta < 17^\circ\!.55'$ and $19^h\!.26.7^m < \alpha < 19^h\!.27.5^m$.

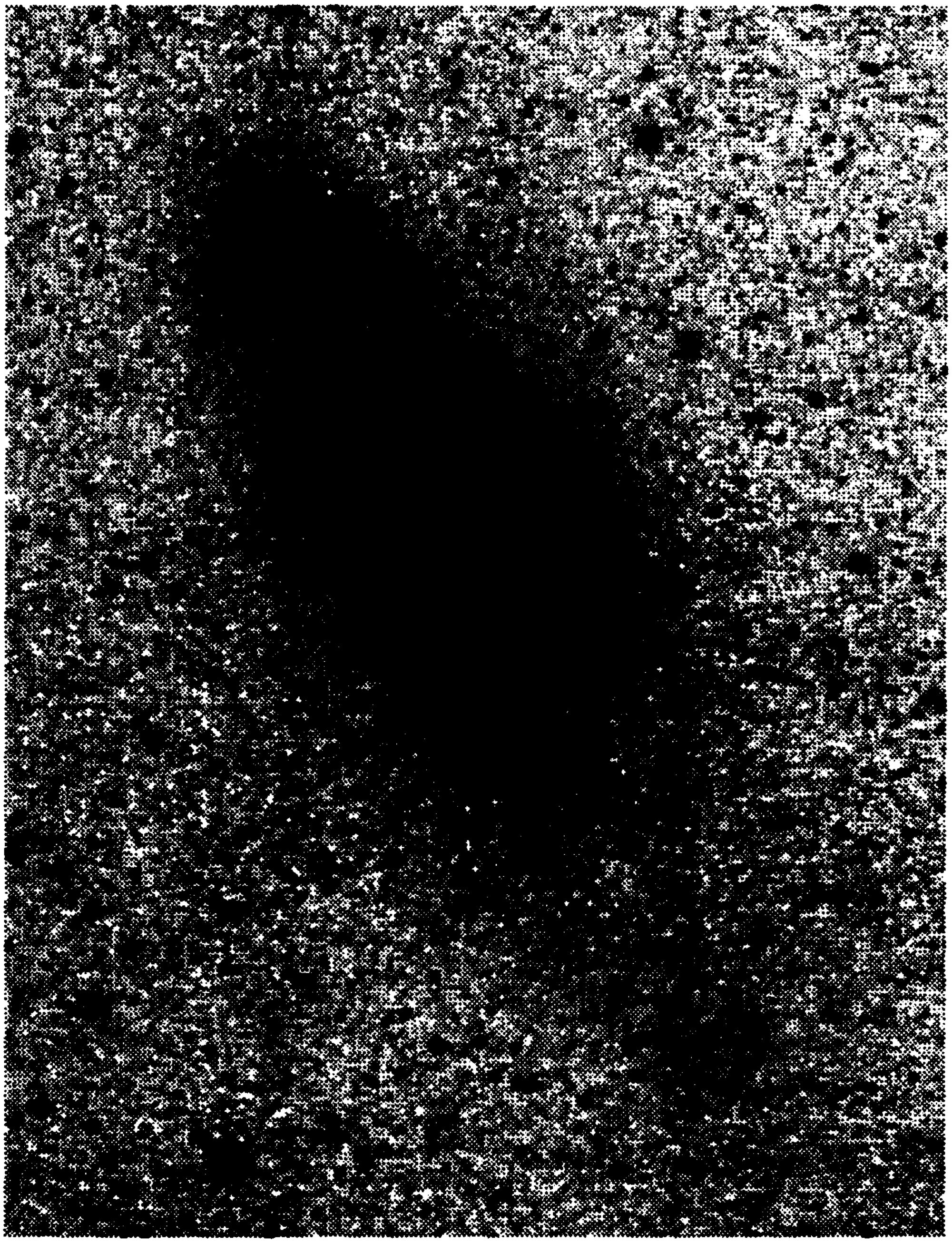


Figure 2. Our K_s-band survey mode image of Maffei 2.

print shows that all of the brighter optically detected galaxies are easily visible on the $2\mu m$ image. This is extremely impressive considering the ratio of exposure times in the images—about 45 minutes for the POSS plate and 7.5 seconds for the 2MASS scan.

Tests of stellar photometry have also been done and provide a benchmark for the detection limits for point sources. In the configuration described above, 2MASS will reach a S/N of 10 for stars of $J \leq 15.3$, $H \leq 15.1$, and $K_s \leq 14.3$.

4. THE ABELL 262 FIELD

Perhaps the most critical experiment that we have performed with respect to the detection and selection of galaxies is the analysis of an 11 square degree field near Abell 262. The preliminary results presented here were derived by applying the FOCAS algorithm to extract nonstellar objects from the 2MASS images. FOCAS was developed by Tyson and Jarvis (1979; see also Jarvis and Tyson 1981) to count faint galaxies on photographic plates, and has since become one of the standard image classification algorithms and is implemented in IRAF. We are currently trying additional techniques. Here, we present some preliminary results from the A262 field.

Over 200 objects were found having $K_s \leq 13.5$. Figure 4 compares the distribution of our K_s-selected objects to optically selected galaxies from the Zwicky catalogue (1961-8). Essentially all the objects in the Zwicky catalogue are detected in K_s to a limit of 13.5. At that limit there are approximately 4 times as many K_s- selected objects as B selected objects. We detect 30, 48, 86 and 220 galaxies to K_s limits of 11.5, 12, 12.5 and 13.5, respectively.

For those galaxies detected in both samples, we can compare the B and K_s magnitudes. Figure 5 is a plot of B_{Zwicky} versus K_s. The Zwicky magnitude scale has been checked by several authors (e.g. Huchra 1976). The approximate linearity of the plot as well as the near unit slope is an indication that the magnitudes are moderately well measured. The scatter is representative of the range in B-K_s colors of galaxies. The average B-K_s is $\sim$3.5, consistent with the known optical-IR colors of galaxies (Aaronson 1978).

We also have measured redshifts for 52 of the 86 galaxies brighter than K_s=12.5 (and will measure redshifts for the fainter galaxies this fall). The mean absolute K_s magnitude, M_{K_s}, is -24.3 (for H_0 = 50 km/s/Mpc) or -22.9 (for H_0 = 100). These numbers, too, are consistent with a mean B-K_s = 3.5 and a characteristic luminosity, M^*_B = -19.4 (deLapparent, Geller and Huchra 1989).

We can also use the overlapping scans in this region to determine the *internal* error in magnitude determination. Figure 6 shows the cumulative magnitude difference distribution between multiple scans. The two lines are for different detection thresholds. For a 3σ threshold, the distribution is indicative of a scatter of only 0.11 magnitude. At a lower detection threshold, 2.5σ, the derived scatter rises, as expected, to 0.18 magnitude.

5. SUMMARY

Although preliminary, these results confirm our ability to detect galaxies to limits significantly deeper than existing optical surveys. More work is needed

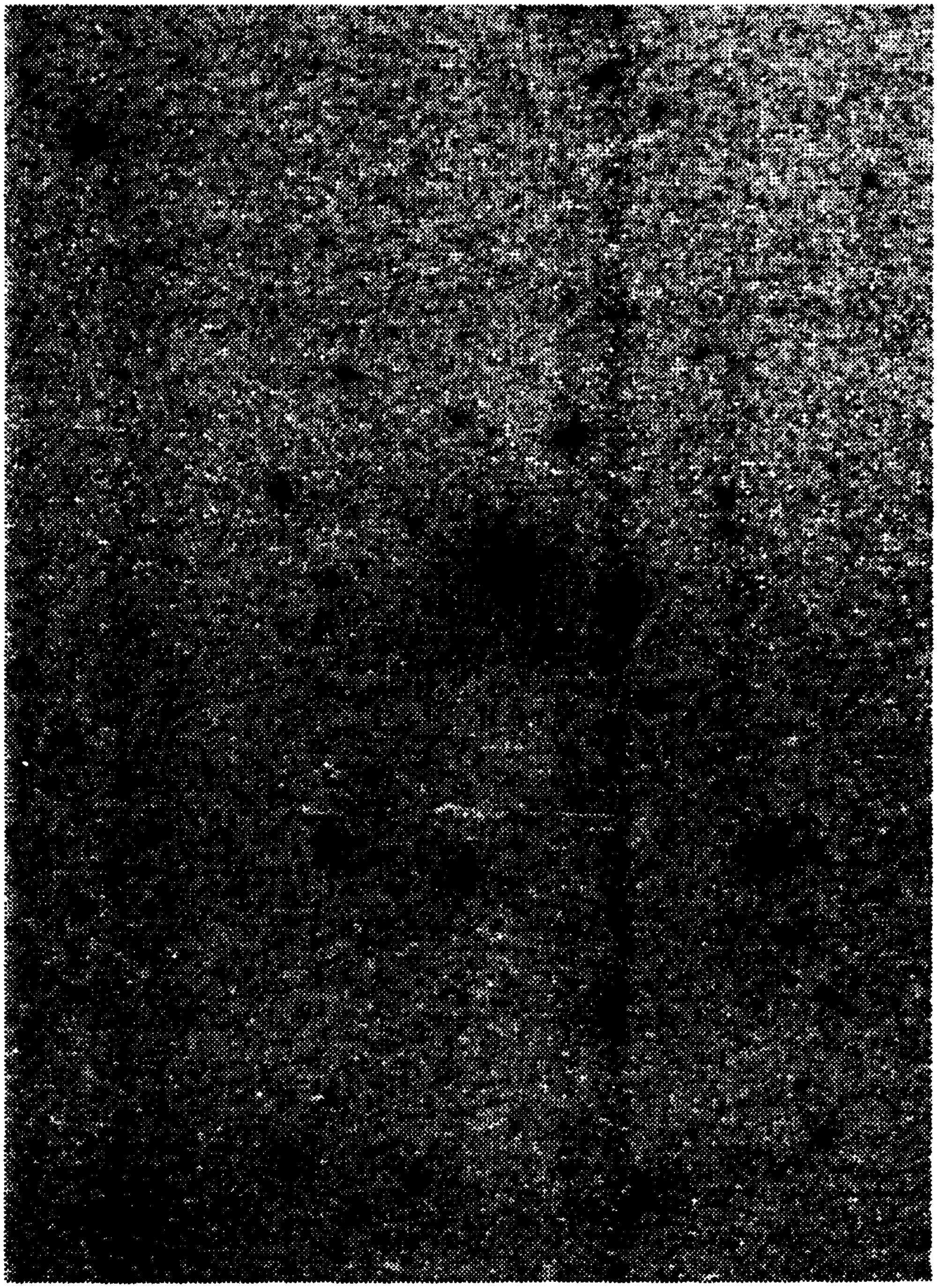


Figure 3. The K_s-band survey mode image of a central region of the Coma cluster of galaxies.

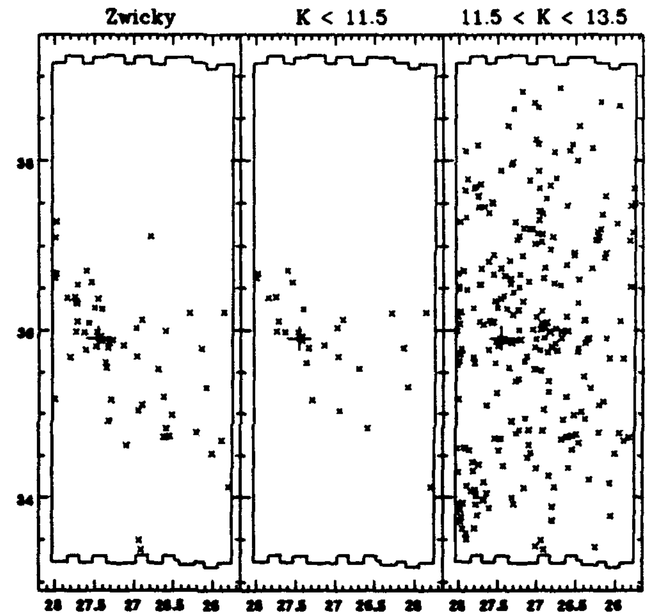
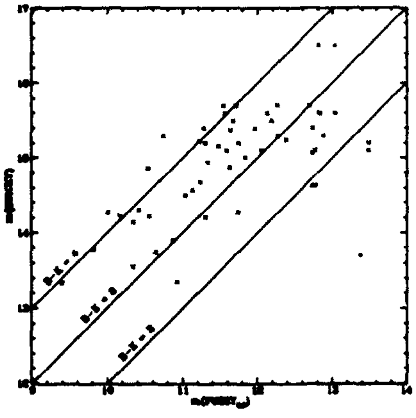


Figure 4. *Left:* All galaxies in the A262 scans with B $\leq$ 15.7 from the Zwicky catalogue. *Center:* All galaxies with $K_s \leq 11.5$ in the same region. Note the similarity in the surface distribution of these bright galaxies. There are approximately 50% as many galaxies to K_s=11.5 as to B=15.7. *Right:* Galaxies with 11.5<K_s<13.5. There are about 4 times as many K_s-selected galaxies to this limit than in the Zwicky catalogue. The fainter galaxies are also much more uniformly distributed on the sky indicating that they are likely background to the A262 cluster.



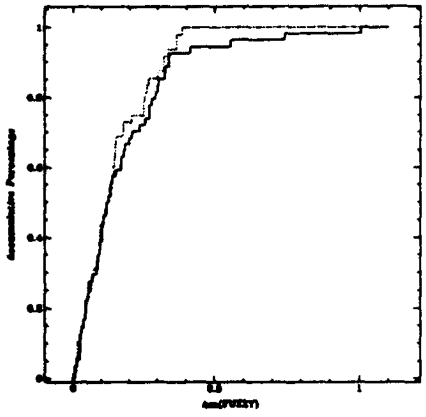


Figure 5. Zwicky magnitude versus K_s-band magnitude for jointly selected galaxies.

Figure 6. The cumulative distribution of magnitude differences in overlapping scans. The solid line is the result from 2.5σ detections, the dotted line is for 3.0σ detections.

to determine the true completeness limits of the 2MASS survey, but it appears as if we are easily complete to at least K_s=12.2 from the comparison with the optical catalogs. If our measured galaxy surface density to K_s=13.5 in the A262 region is representative—220 galaxies in 11 square degrees—2MASS will detect and catalog over 500,000 galaxies. If we can combine the JHK_s scans to produce a deeper catalog, the number will be much higher. In either case, we expect 2MASS to be an outstanding tool for probing the galaxy distribution through the Zone of Avoidance.

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